AN INVESTIGATION OF THE EFFECTS OF AN ASPHALTIC EMULSION AS AN ADMIXTURE ON THE PROPERTIES OF PORTLAND CEMENT CONCRETE

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A thesis
presented to the faculty of
Rensselaer Polytechnic Institute
in partial fulfillment of the
requirements for the degree of
Master of Civil Engineering

by

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INTRODUCTION

Concrete construction has assumed a major position in modern civil engineering design. Because of its flexibility of use, architectural values, and general availability concrete is used even in instances where it might be inferior in some respects to other materials and methods of construction. Consequently, the general subject of improving concrete mixtures has been given considerable attention.

The idea of experimenting with bituminous admixtures in concrete is not original with the authors. Previous investigators have made thorough studies of such mixtures as a means of physically waterproofing concrete by the dispersion of the bituminous product throughout the pores of the concrete. Such was the work of Mr. Sanborn and Mr. Taylor, conducted in 1913. Their tests showed reduced permeability with an attendant reduction of strength. Mr. Taylor and Mr. Sanborn used a series of bituminous oils in varying quantities and confined their experiments to one general classification of oils.

In Germany prior to the second World War, considerable work was done on the use of bituminous products in concrete for highway work. German engineers were concerned with the effects of repetitive freezing and thawing on concrete and its strength. References to this work are appended below.

This thesis attempts to expand on previous work and to make a study with perhaps an entirely new object. Full credit

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should be given to Mr. H. J. Grathwol of Silver Spring, Maryland, for his original idea of using an asphalt emulsion as an admixture for the purpose of controlling temperature stresses in concrete. Mr. Grathwol, after his theoretical considerations, contacted Professor H. O. Sharp, of Rensselaer Polytechnic Institute, and the subject was deemed worthy of presentation for a master's thesis.

Complete results cannot be achieved here, however. Time limitations have fixed the scope of the work. In investigating a subject as broad as the use of admixtures in concrete, various arbitrary choices have to be made in order to reduce the variables. In the types and kinds of asphaltic emulsions alone there are far too many to give consideration to each. In the kinds of aggregate the situation is no better. Moreover, some of the important tests, notably expansion, could not be performed because they required six months or more for completion. As a result certain tests were selected using known standards and correlating the results on a comparative basis.

After a study of available research material in the Rensselaer Polytechnic Institute library and the Engineering Societies Library in New York City, the writers confined the scope of the investigation to work which it is hoped will add to the present knowledge of asphaltic emulsion as an admixture. The objectives are: to study the reaction between a bituminous emulsion and concrete mixtures by testing the physical properties of the resulting concrete; to determine the percentages

of emulsion producing the most desirable properties; to study the disperse phase of the asphalt particles; to study air entrainment.

The experimental work consists of a series of tests applied to specimens of varying composition, age, and treatment. Different methods of handling the asphalt emulsion, mixing the concrete, and obtaining consistencies were tried, as is explained below. Whenever possible the procedures recommended by the American Society for Testing Materials were followed. Whenever this was not the case, the reasons for and description of the procedure used are given.

As stated before, the work presented here is necessarily that done in one school semester. The results cannot be complete, but they are intended to be a contribution to a very important phase of the profession of Civil Engineering.

PHASE I

METHOD FOR DETERMINING OPTIMUM ASPHALTIC EMULSION CONTENT

The first test that was made was to determine the amount of asphalt emulsion to be added to the concrete mix. This was done by testing the cement mortar, using as a maximum the quantity of emulsion, expressed as a percent by weight of Portland Cement, until the strength of the specimen was approximately equal to the strength of a 1:3 mortar mix without the admixture of emulsion. It was decided to do this by following the Standard Method of Sampling and Physical Testing of Portland Cement ASTM Designation C 77-40. In this test a quantity of the cement to be used throughout the laboratory work was first sieved through a number 20 sieve. Standard Portland Cement estimated to be about six months old was used. Three series of briquets were made, one with standard Ottawa sand, the second with a sample of the sand to be used for all the tests which was Cow Bay sand with a sieve analysis as given elsewhere in this report. The third series of briquets was made up of cement mortar briquets with percentages of asphalt as follows: One, Two, Three, Four, Six, Eight, Ten, Twelve percent of emulsion. The large range was required since nothing was known of the quantity of emulsion required to give a strength approximately equal to the standard 1:3 mortar mix.

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In mixing the Ottawa sand and Cow Bay sand standard briquets, it was first necessary to determine the normal consistency of neat cement. Normal consistency of neat cement is the amount of water required to cause a settlement of the rod of a Vicat apparatus to a point ten millimeters below the original surface in thirty seconds after being released, following the standard procedure for mixing the samples. Several trial mixes were made until the cement was determined to have a normal consistency with thirty percent water. From the table of percentage of water for neat cement paste of normal consistency against percentage of water for mortar of one cement to three standard sand it was found that eleven and one-half percent was required for the standard briquets. At this point it was necessary to decide whether to use an amount of water equal to eleven and one-half percent of the weight of sand and cement and add the emulsion without accounting for the water in the emulsion or to subtract the amount of water in the asphalt and use an additional amount of water to make up the eleven and one-half percent required. The latter was the method followed using an emulsion composed of sixty percent asphalt and forty percent water. Since the briquet moulds were gang moulds each containing three moulds and three samples each of Ottawa sand standard specimens, Cow Bay sand specimens and each percentage of asphalt emulsion, the following amounts of sand, cement and water were used for each batch cast:

Sand - 450 grams

Cement - 150 grams

Water - 69 ml

The following table gives the amount of water for each percentage of asphalt used.

Asphalt Percent	1	2	3	4	6	8	10	12
Grams of Emulsion	6	12	18	24	36	48	60	72
Actual Asphalt	3.6	7.2	10.8	14.4	21.6	28.8	36.0	43.2
Actual Water	2.4	4.8	7.2	9.6	14.4	19.2	24.0	28.8
Required Water	66.6	64.2	61.8	59.4	54.6	49.8	45.0	40.2

The standard mortar was mixed following the ASTM procedure by mixing the sand and cement dry and then adding the water. Again there was no precedent to follow in adding the asphalt emulsion so that in the process of mixing the batches, several different methods were tried. First the water was added to the cement-sand mixture, then the asphalt emulsion was added and the mixture kneaded and placed in the mould. A second method tried was to add the emulsion to the dry sand and cement and then add the water. The third method tried was to mix the water and emulsion together in a separate container and then add it to the cement-sand mixture. The last mentioned was found to be most satisfactory although

it was found difficult to achieve a thoroughly homogeneous mass and some evidence of lumps of asphalt in the mortar was discovered in the mixing process.

As each batch of mortar was mixed it was placed in the gang mould on unoiled glass plates. The moulds were oiled with a thin film of mineral oil before being filled with the mortar paste. The moulds used were standard briquet moulds for tensile strength tests.

After moulding, all test specimens were immediately placed in a moist closet at a temperature of 21 $^{\circ} \pm 1.7 ^{\circ}$ centigrade and at a relative humidity of ninety percent. The specimens were left in the moulds and kept on plane glass plates for a period of twenty-four hours. At the end of this period the specimens were removed from the moist closet and from the moulds and placed under water for a period of six days so that the specimens were aged seven days at the time of testing. The specimens were tested as soon as they were removed from the storage water in a tensile testing machine with the load applied at the rate of six hundred pounds per minute. Briquets which gave strength differing by more than fifteen percent from the average value of all test specimens made from the same mixture were assumed to be faulty and were not considered in determining the tensile strength.

Since the briquets are of the dimensions as shown below, the tensile strength in pounds per square inch was the breaking load of the specimen.

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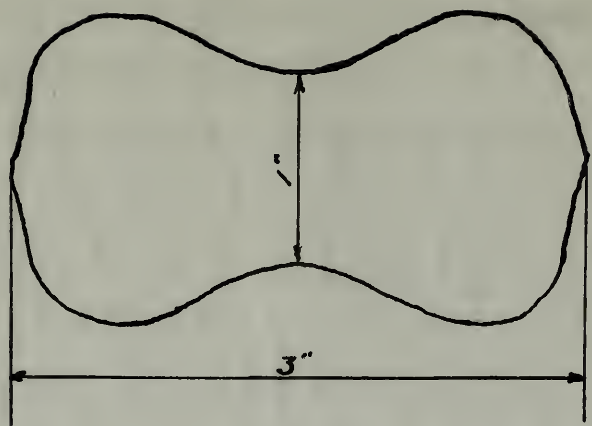
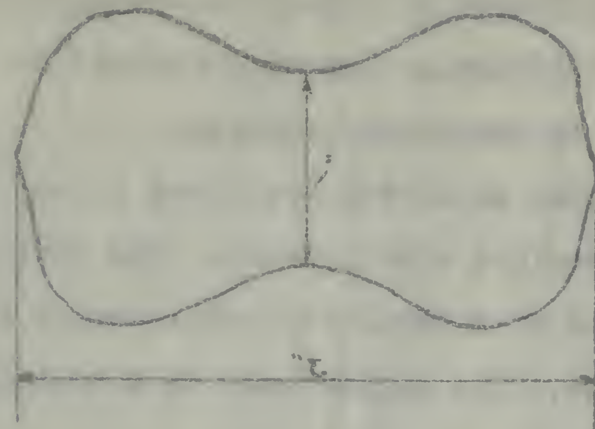


The results of the tensile tests are shown in the graph following and it can be seen that the strength decreases as asphalt emulsion is added in larger amounts. Upon breaking the specimens in the tensile testing machine and examining the fracture, it was seen that in many cases the asphalt emulsion had not completely dispersed throughout the briquets leading to the conclusion that only a small percentage of emulsion could be used in mixing the concrete test specimens. Some concern was felt after discovering the segregation of the asphalt in the mortar briquets but from the known fact that the properties of the bituminous emulsion cause it to adhere to moist coarse aggregate, it was thought that this segregation would not be present when using the emulsion in a standard 1:2:3 concrete mix.

As the curve of tensile strength from this series of tests showed a continuous decrease with the addition of from



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As the curve of tensile strength from this series of tests showed a continuous decrease with the addition of from

zero to twelve percent emulsion it was decided to cast concrete specimens containing zero, one, two and three percent of asphalt emulsion by weight of sand, stone and cement.

ANALYSIS OF ASPHALT EMULSION USED

Item No.	70 B
Grade	B
Water Percent	45 -
Asphalt Percent	55 ±
Homogeneous	Yes
Specific Gravity @ 77 °F	1.00 ±
Ash Percent	2.0 -
Furol Vis. @ 77 °F	30-65
Miscibility	-
Settlement, five days	3.0 -
Stone Mixing	--
Setting	Yes
Cement Mixing	--
Screen Test Percent	0.1 -
Demulsibility N/10 Percent	--
Demulsibility N/50 Percent	60 ±

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Miscibility	-
Settlement, five days	3.0 -
Stone Mixing	--
Setting	Yes
Cement Mixing	--
Screen Test Percent	0.1 -
Demulsibility N/10 Percent	--
Demulsibility N/50 Percent	40 ±

PHASE II

PROCEDURE FOR MIXING, MOULDING, AND TESTING CONCRETE SPECIMENS.

Since the tension tests performed on the briquets (see curve) clearly indicated that increased quantities of the emulsion decreased the strength properties of the mortar, it was initially assumed that the same results would hold true for a concrete mixture using both coarse and fine aggregate. However, it was hoped that with the addition of the coarse aggregate somewhat better results would be obtained, because of the known affinity of asphaltic emulsions for moist stone. This affinity was lacking when sand alone was used. Furthermore it was also hoped that the segregation of the asphalt might also be remedied due to this same affinity. Therefore, it was decided to mould test samples containing emulsion equivalent to one, two and three percent of the total weight of sand, stone and cement in the mix.

For test purposes, a series of standard six by twelve inch concrete cylinders and a similar series of concrete beams six by six by twenty-four inches were cast. These series consisted of groups of three samples containing no emulsion, three containing one percent, three with two percent and three with three percent, a total of twelve cylinders and twelve beams. Similar groups were cast and cured for a period of seven days, twenty-eight days and forty-five days. It would have been desirable to have a longer curing period for certain of the groups in order to determine the effects of age on the concrete, but due to time limitations it was

necessary to limit the longest curing period to the aforementioned forty-five days.

The best materials obtainable were used throughout the moulding of the specimens. The fine aggregate was Cow Bay sand from Port Jefferson, Long Island, an analysis of which is appended to this section. In choosing the coarse aggregate, it was felt that a desirable standardization of specimens would be obtained by using a one-size aggregate, even though this would mean a sacrifice of strength. A sacrifice of strength was inconsequential, however, because the results are comparative. Therefore, a clean, sharp, crushed limestone aggregate which passed through a one-half inch mesh screen and was retained on a three-eighths inch mesh screen was used. Portland cement, clean water and asphalt emulsion comprised the remaining materials. The emulsion was obtained from Mr. E. C. Ketchum of the Socony Vacuum Oil Co., Inc., Albany, New York, an analysis of which has been given under Phase I of this text.

Due to space limitations it was necessary to carry on the work of moulding and curing the specimens at the U. S. Naval Supply Depot, Scotia, New York. Fortunately a heated building was obtained as well as a seven cubic foot power mixer. The heated building meant the difference between carrying on this work and abandoning it because of the severe cold weather. The mixer facilitated the accurate and thorough mixing of large amounts of concrete.

A 1:2:3 mix was used throughout and all quantity measurements were made to an accuracy of one ounce. Regarding the question of workability, a three-inch slump was used for each batch. This was obtained by using the minimum possible addition of water combined with asphalt emulsion. In this manner the water-cement ratio was kept a minimum with a consequent maintenance of maximum strength for each specimen group. By thus allowing for the "break down" of the emulsion, sufficient water of hydration was assured.

In all cases, an attempt was made to simulate probable field conditions as regards methods of mixing while at the same time devoting stringent attention to laboratory techniques and accuracy. The greatest difficulty in this respect was in the method of applying the asphaltic emulsion. As explained heretofore, during the moulding of the mortar briquets, many methods of adding the emulsion were used. The best of these resulted in vigorously stirring the emulsion into the water and adding the resulting solution to the sand and cement. Water at room temperature was successfully used in this case probably because of the small amounts of emulsion used. Yet, when the same method was attempted with the larger amounts required for a three cubic foot batch, the emulsion broke down and a large lump of asphalt immersed in water was the result. The reason for this action is not definitely known. However, it is the opinion of the authors that large amounts of the emulsion will not go into solution unless the water is heated. Another method, which proved successful, was to add

the required amount of emulsion to the wet mix. Satisfactory distribution was thus obtained with no visible segregation in the wet concrete from the mixer. The resultant success in the use of this method is most probably due to the affinity of the emulsion for wet stone. This method was deemed more desirable than heating the water since it more nearly simulated the probable field method. It was hoped, at this point, that due to this same affinity, the segregation of the asphalt, as noted in the mortar briquets, would not occur in the concrete. A further discussion of the possibilities of adding asphaltic admixtures is included in the conclusions to this thesis.

In moulding the concrete beams, wooden forms were used, whereas for the cylinders standard six inch by twelve inch steel moulds were used as well as six by twelve inch cardboard cylinders procured from the Cleveland Container Corporation, 601 West 26th Street, New York City. ASTM specified methods were used in that the concrete was poured in three equal layers and each layer was rodded twenty-five times throughout its depth. In conjunction with this, the sides of the wooden moulds and the cylinders were tapped with a maul in order to assure that the concrete would adhere to the sides of the moulds and voids would be eliminated. The excess concrete was struck off the moulds and the surface finished with a minimum of troweling.

The specimens were cast during the period from March 6, 1948 to April 3, 1948. The forty-five day samples were cast first, then the twenty-eight day samples and finally the

seven day specimens. All specimens were removed from the forms within from twenty-four to forty-eight hours after pouring. Curing was accomplished by two methods: one was to completely cover the specimens with sand which was kept wet continuously and the other was by wrapping the specimens in wet burlap sacks, keeping them continuously wet also. All specimens were cured in this manner until the day of testing.

After the specified curing periods the specimens were transported from Scotia, New York to the Materials Testing Laboratory at Rensselaer Polytechnic Institute, Troy, New York. The concrete beams were tested for bending strength at the extreme fiber. Since all specimens were of exactly the same dimensions, the results are reported herein as simply the breaking load. A hand-balanced Olsen Testing Machine was used throughout the tests. Each beam was centered on two knife edges spaced at a distance of eighteen inches. A third knife edge was attached to the movable head of the machine and bore on the center of the beam, twelve inches from each end. Flat steel plates two inches by eight inches by one-quarter inch were inserted between each knife edge and the beam in order to prevent gouging of the beam by the knife edge. A linkage type strain gage with a linkage ratio of ten to one was connected between the movable head and the stationary supporting arm of the machine in order to give deflection readings of the beam centers. The clutching arrangement was set to give a head travel speed of 0.05 inches per minute.

The test cylinders were tested on a standard Olsen Compression Testing Machine with the load applied at the rate of five thousand pounds per minute. Each cylinder was capped before testing with Plaster of Paris in order to give a smooth, level bearing surface on each end of the cylinders.

In view of the relatively recent knowledge of the importance of controlling the amount of air entrained in concrete mixtures, it was desired to determine what effect, if any, asphaltic emulsion would have on this property. The authors were fortunate in obtaining from the Research Laboratories of the Portland Cement Association one of their pressure measuring devices. A complete description of this apparatus with instructions for its use is contained in that organization's Bulletin 19 entitled "Procedure for Determining the Air Content of Freshly-Mixed Concrete by the Rolling and Pressure Methods" by Carl A. Menzel. This method is easier to apply and more accurate than the gravimetric method. As each batch of concrete, plain and with various percentages of emulsion was taken from the mixer, a test was conducted to determine the air content and the results are reported herein. Before use, the apparatus was calibrated for the area in which the tests were conducted.

SIEVE ANALYSIS OF COW BAY SAND

Used In Moulding Concrete Specimens

Sieve Number	Weight Retained	Percent Retained	Percent Passing
8	1.000	2.79	97.21
16	6.563	18.34	78.87
30	10.563	29.50	49.37
50	13.563	37.85	11.52
100	3.563	9.95	1.57
Passing	.563	1.57	
	35.815	100.00	

PHASE III

FREEZE-THAW TEST OF CONCRETE SPECIMENS

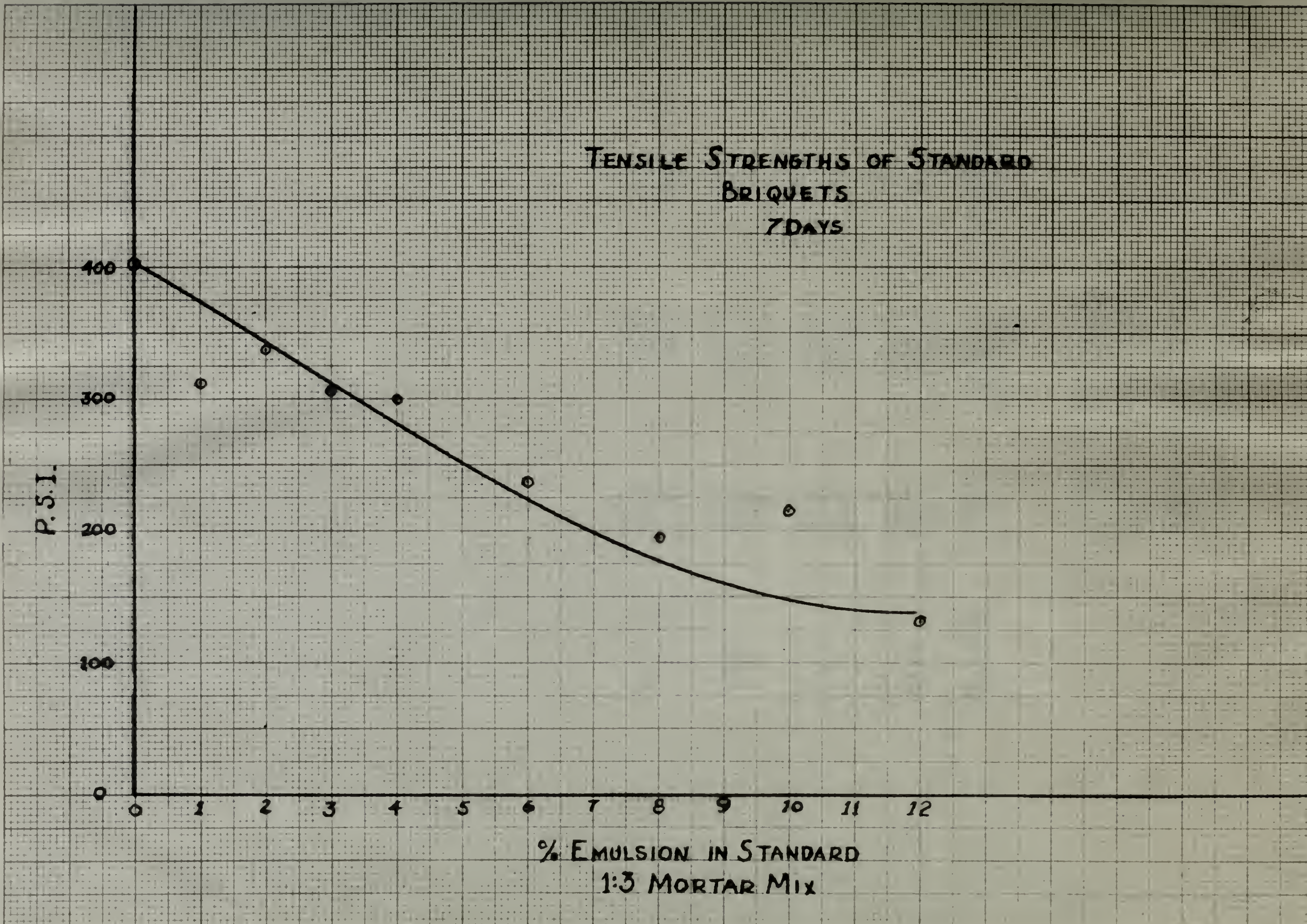
With the knowledge that entraining an optimum percentage of air improves the durability of Portland cement concrete, it was felt that valuable data could be obtained from a freeze-thaw test. As far as the authors could determine no standard laboratory test of this nature was available at the time. A simple test was devised therefore, which consisted of subjecting three inch by six inch test cylinders to repeated freezing and thawing. The cylinders were placed in a refrigerator at a temperature of 5 °F for a period of twenty-four hours. They were then removed and placed in an oven at a temperature of 120 °F and left therein for the same period. After three such cycles, this test was interrupted and compression tests were conducted, the results of which are included elsewhere in this text. The tests indicated that the strengths of these samples compare with those of the normally cured specimens. There was no weight reduction at this time and no visible scaling or spalling. This was as expected. A much greater number of cycles would be needed for conclusive results.

SEVEN DAY TENSILE STRENGTHS
OF STANDARD BRIQUET SPECIMENS

CAST February 17, 1948

TESTED February 24, 1948

Type	Percent Asphalt	Sample Number	Tension P.S.I.	Average
1:3 Mortar Mix		1	266	
Ottowa Sand	0	2	264	268
		3	275	
1:3 Mortar Mix		1	403	
Cow Bay Sand	0	2	406	403
		3	401	
		1	304	
	1	2	369	316
		3	274	
		1	315	
	2	2	329	335
		3	362	
		1	249	
	3	2	340	305
		3	325	
		1	298	
	4	2	316	300
		3	287	
		1	218	
	6	2	295	234
		3	190	
		1	185	
	8	2	180	198
		3	230	
		1	202	
	10	2	238	221
		3	224	
		1	181	
	12	2	106	129
		3	102	

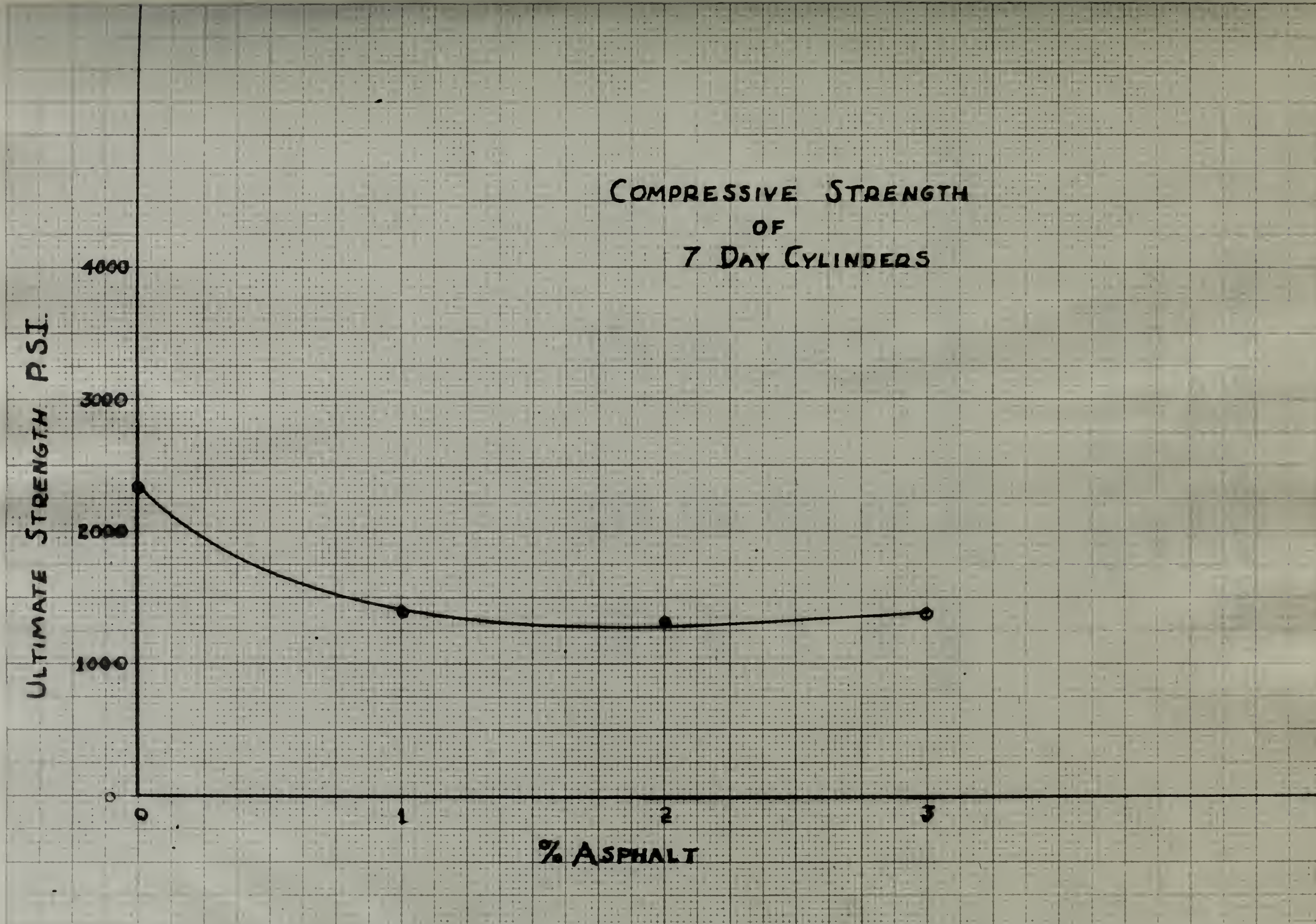

TENSILE STRENGTHS OF STANDARD
BRIQUETS
7 DAYS
P.S.I.
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
12
% EMULSION IN STANDARD
1:3 MORTAR MIX

COMPRESSIVE STRENGTH
of
SEVEN DAY CYLINDERS

CAST April 3, 1948

TESTED April 10, 1948

Percent of Asphalt	Breaking Load	P.S.I.	Average
	63600 lb	2255	
0	69200	2450	2332
	64600	2290	
	37600	1221	
1	41300	1462	1391
	39000	1381	
	36600	1297	
2	36600	1297	1231
	31100	1100	
	39000	1381	
3	39000	1381	1387
	39500	1400	


COMPRESSIVE STRENGTH
OF
7 DAY CYLINDERS
ULTIMATE STRENGTH P.S.I.
4000
3000
2000
1000
0
0
1
2
3
% ASPHALT

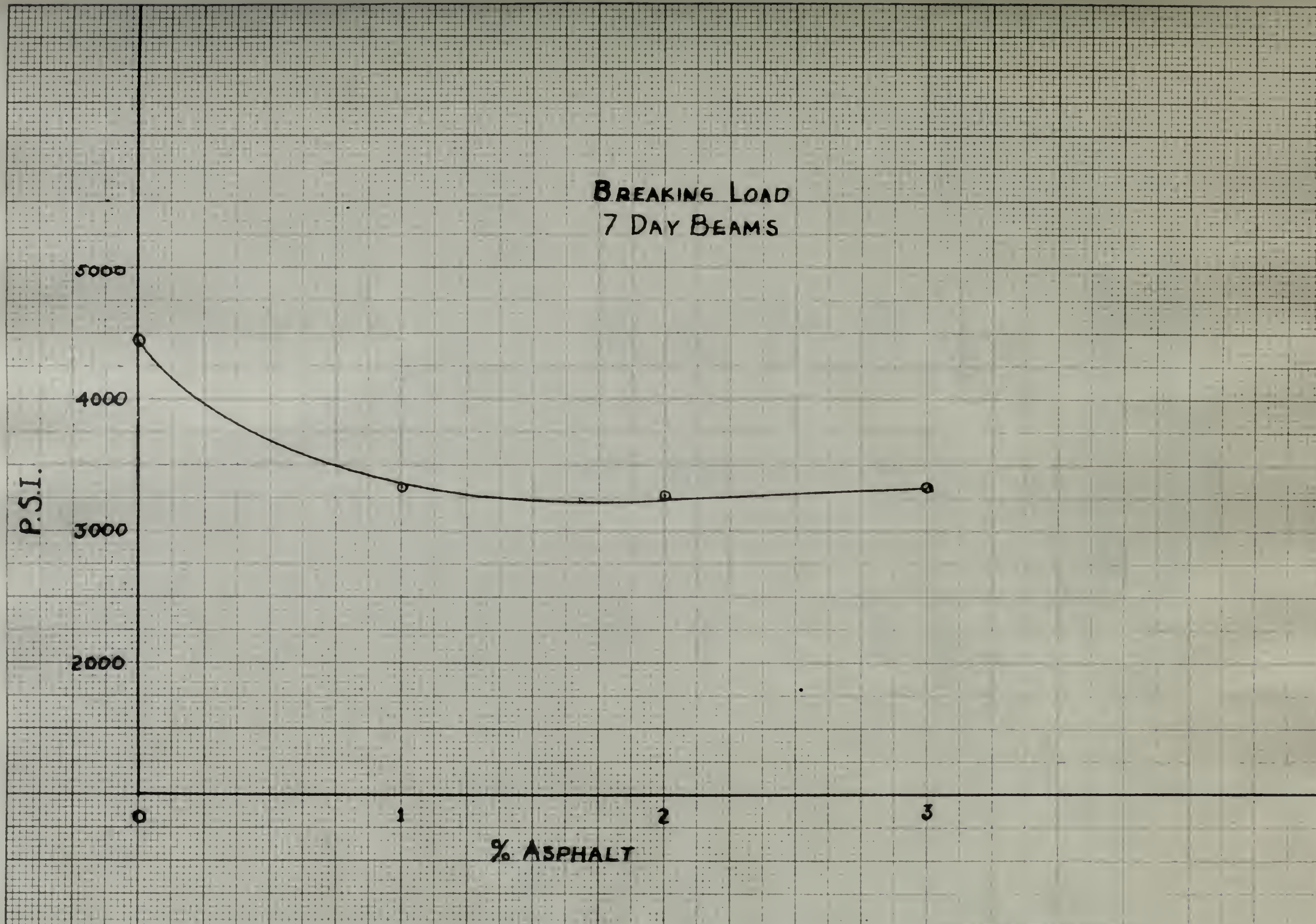
DEFLECTION AND BREAKING LOAD

SEVEN DAY BEAMS

CAST April 3, 1948

TESTED April 10, 1948

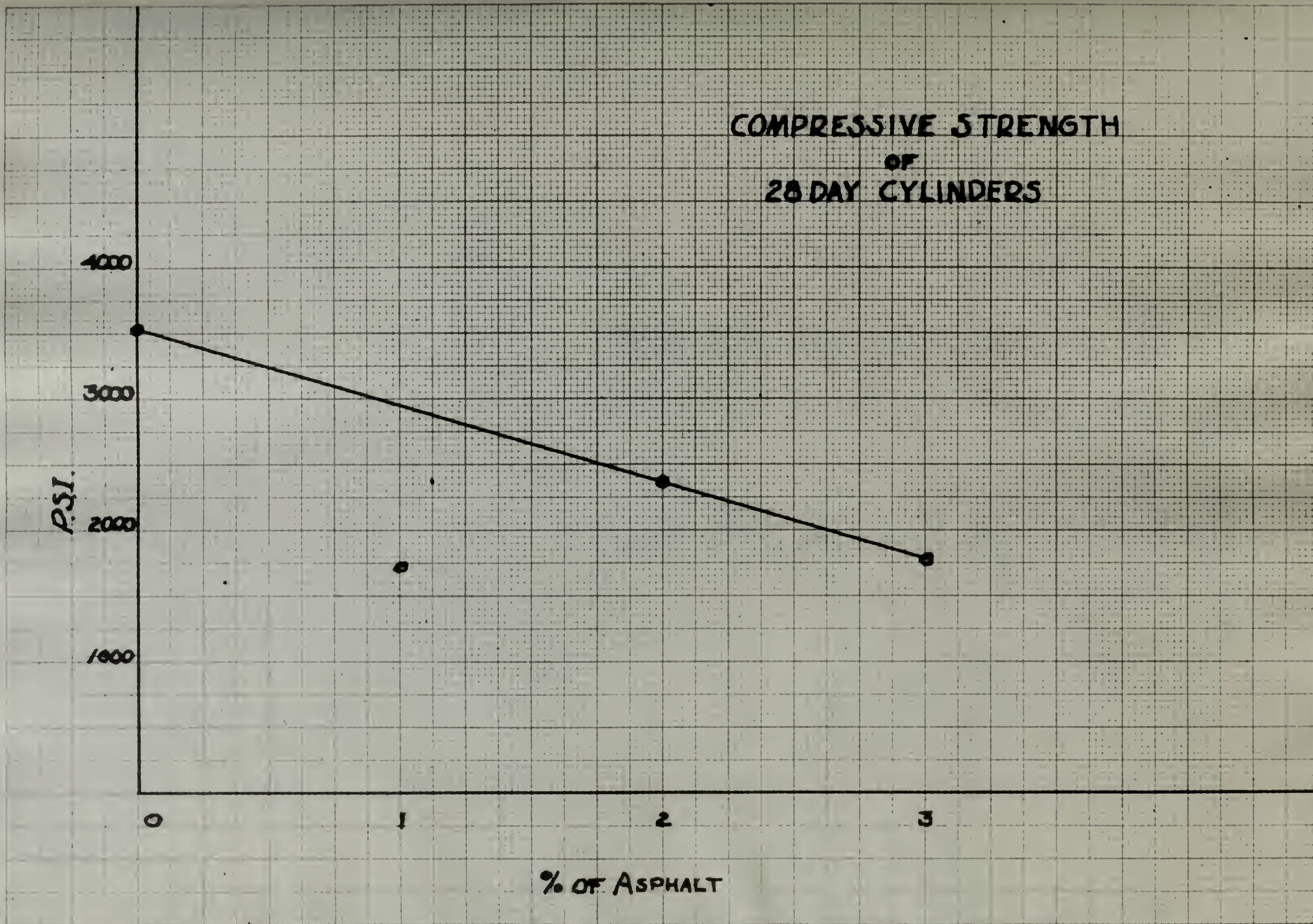
Percent of Asphalt	Deflection	Breaking Load	Average
	.055 In.	3600	
0	.085	4870	4423
	.060	4800	
	.065	3350	
1	.055	3350	3310
	.055	3230	
	.080	2750	
2	.070	3360	3260
	.090	3670	
	.055	3075	
3	.070	3440	3362
	.060	3570	


BREAKING LOAD
7 DAY BEAMS
P.S.I.
5000
4000
3000
2000
0
1
2
3
% ASPHALT

COMPRESSIVE STRENGTH
of
TWENTY-EIGHT DAY CYLINDERS

CAST March 12-13, 1948
TESTED April 9-10, 1948

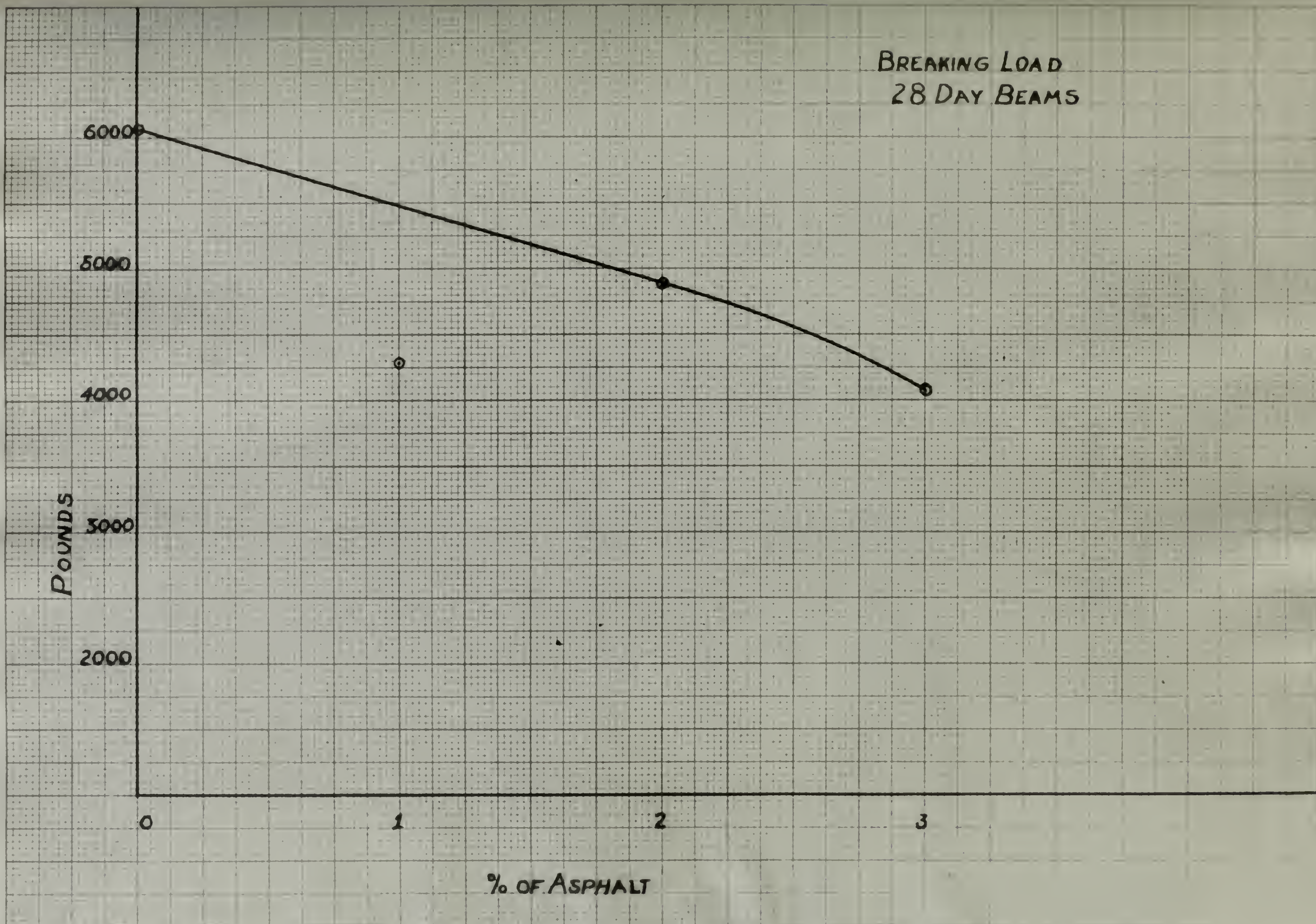
Percent of Asphalt	Breaking Load	P.S.I.	Average
	98400	3480	
0	100500	3560	3525
	99800	3535	
	48400	1750	
1	48000	1700	1726
	48900	1730	
	72700	2575	
2	66600	2360	2393
	63500	2245	
	52900	1870	
3	50000	1770	1773
	47700	1690	


COMPRESSIVE STRENGTH
OF
28 DAY CYLINDERS
P.S.I.
4000
3000
2000
1000
0
1
2
3
% OF ASPHALT

DEFLECTION AND BREAKING LOAD
TWENTY-EIGHT DAY BEAMS

CAST March 12-13, 1948
TESTED April 9-10, 1948

Percent of Asphalt	Deflection	Breaking Load	Average
	.07 In.	6070 Lb.	
0	.07	7150	6074
	.07	6078	
	.08	4170	
1	.05	5100	4270
	.06	4370	
	.08	5050	
2	.06	4960	4876
	.06	4620	
	.06	4078	
3	.06	4080	4079
	.05	4655	

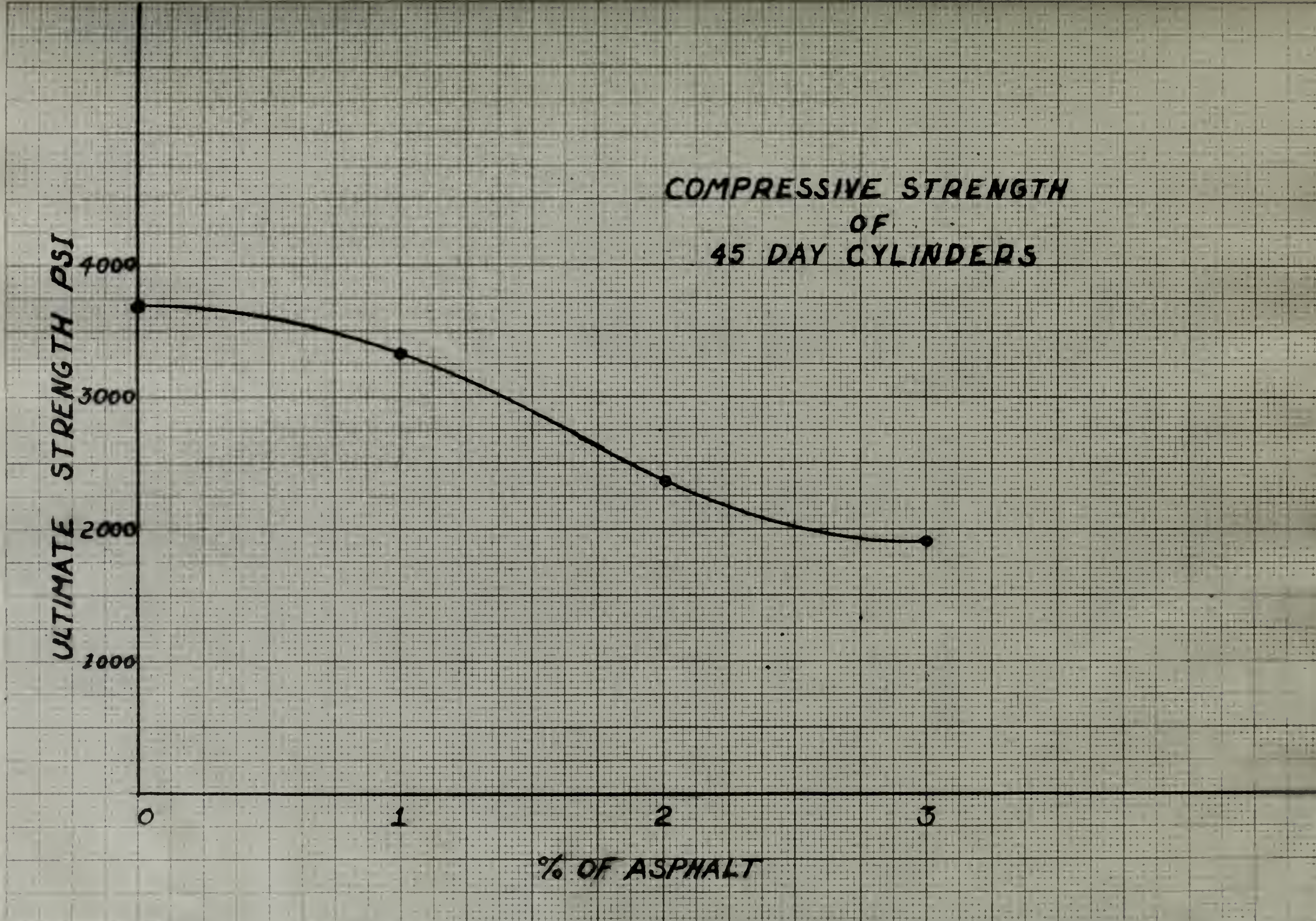

BREAKING LOAD
28 DAY BEAMS
6000
5000
4000
3000
2000
POUNDS
0
1
2
3
% OF ASPHALT

COMPRESSIVE STRENGTH
of
FORTY-FIVE DAY CYLINDERS

CAST March 5-6-7, 1948

TESTED April 19-20-21, 1948

Percent of Asphalt	Breaking Load	P.S.I.	Average
	117000	4150	
0	102400	3630	3687
	92750	3280	
	103600	3665	
1	83500	2960	3345
	96350	3410	
	66700	2365	
2	63600	2255	2363
	69700	2470	
	51400	1820	
3	53300	1890	1910
	57000	2020	

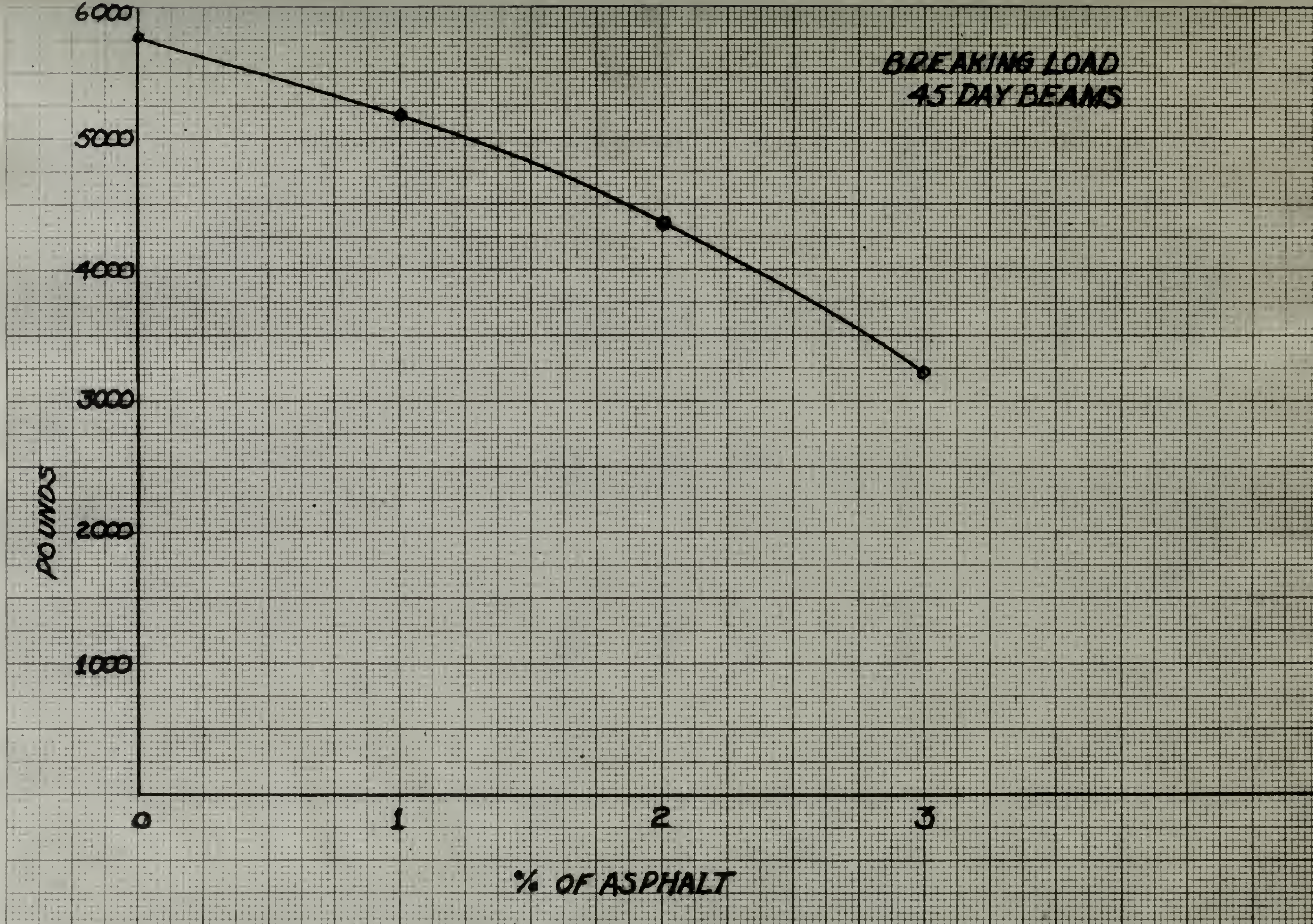

COMPRESSIVE STRENGTH
OF
45 DAY CYLINDERS
ULTIMATE STRENGTH PSI
4000
3000
2000
1000
0
1
2
3
% OF ASPHALT

DEFLECTION AND BREAKING LOAD
FORTY-FIVE DAY BEAMS

CAST March 5-6-7, 1948

TESTED April 19-20-21, 1948

Percent of Asphalt	Breaking Load	Deflection	Average
	0.100	5170	
0	0.110	5560	5777
	0.080	6600	
	0.072	5030	
1	0.070	5285	5158
	0.065	6330	
	0.055	4000	
2	0.065	4700	4350
	0.065	4350	
	0.060	3240	
3	0.060	4110	3205
	0.060	3170	

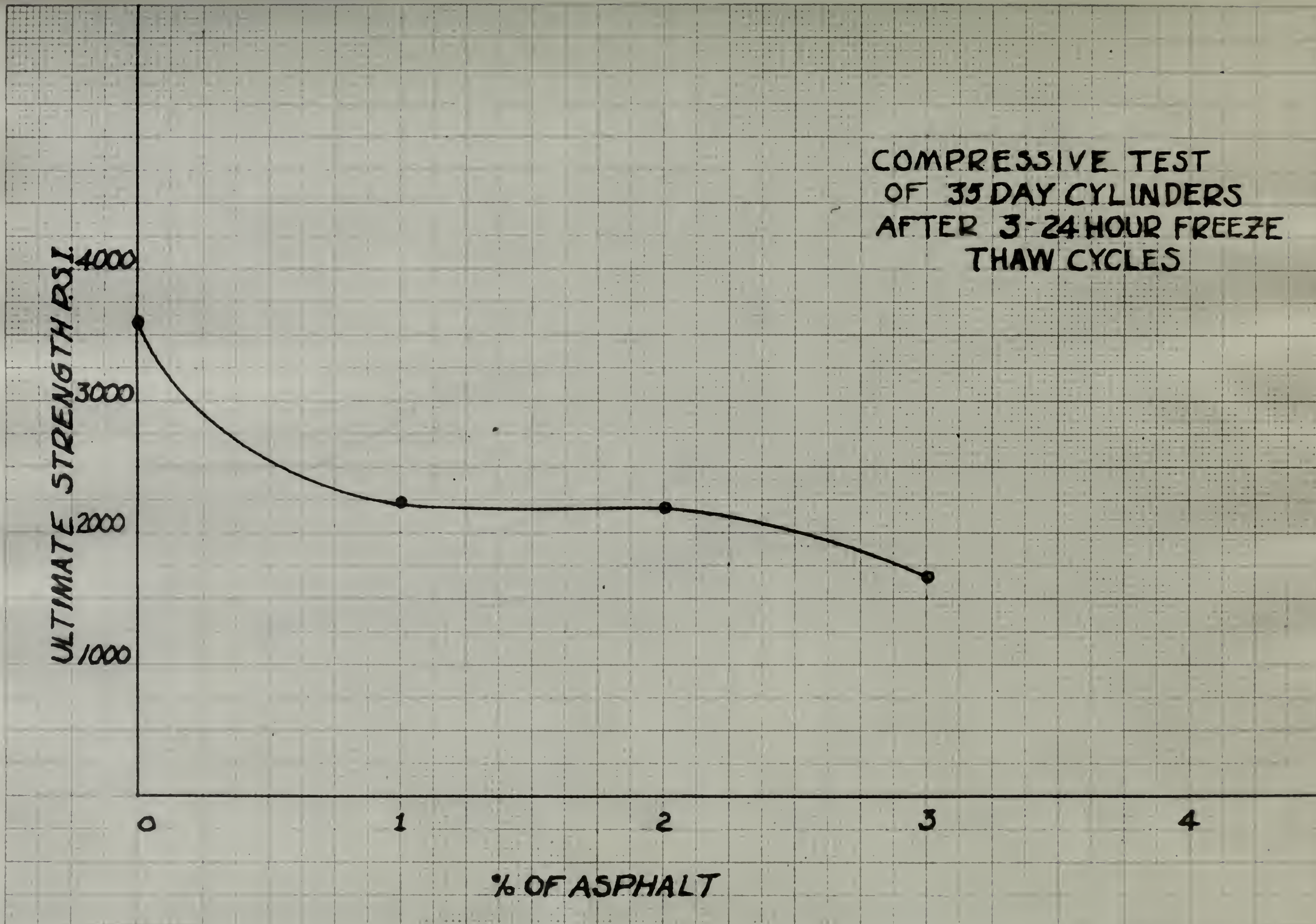

BREAKING LOAD
45 DAY BEAMS
6000
5000
4000
3000
2000
1000
POUNDS
0
1
2
3
% OF ASPHALT

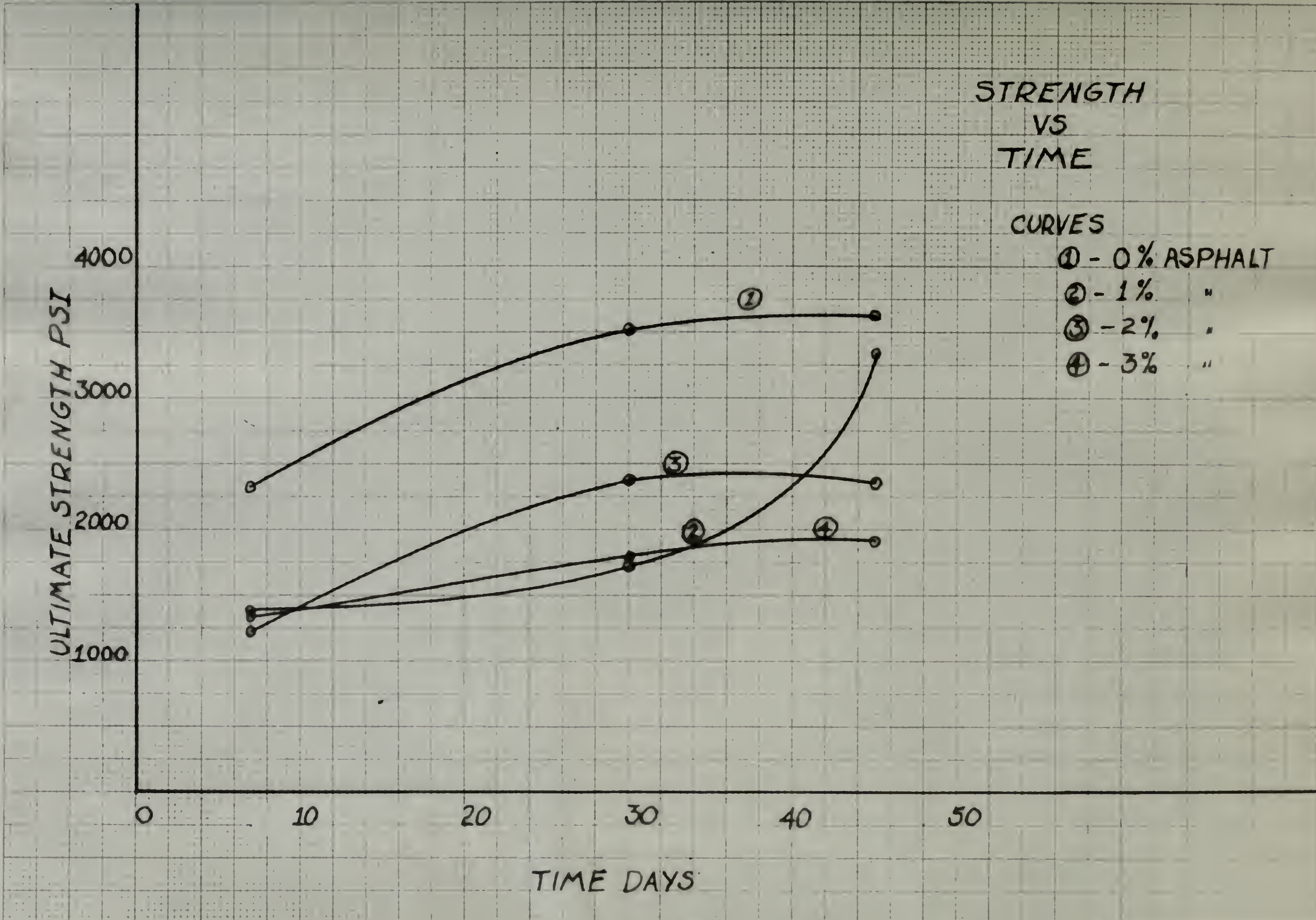
COMPRESSIVE STRENGTH OF
THIRTY-FIVE DAY CYLINDERS
AFTER THREE TWENTY-FOUR HOUR
FREEZE-THAW CYCLES

CAST April 3, 1948

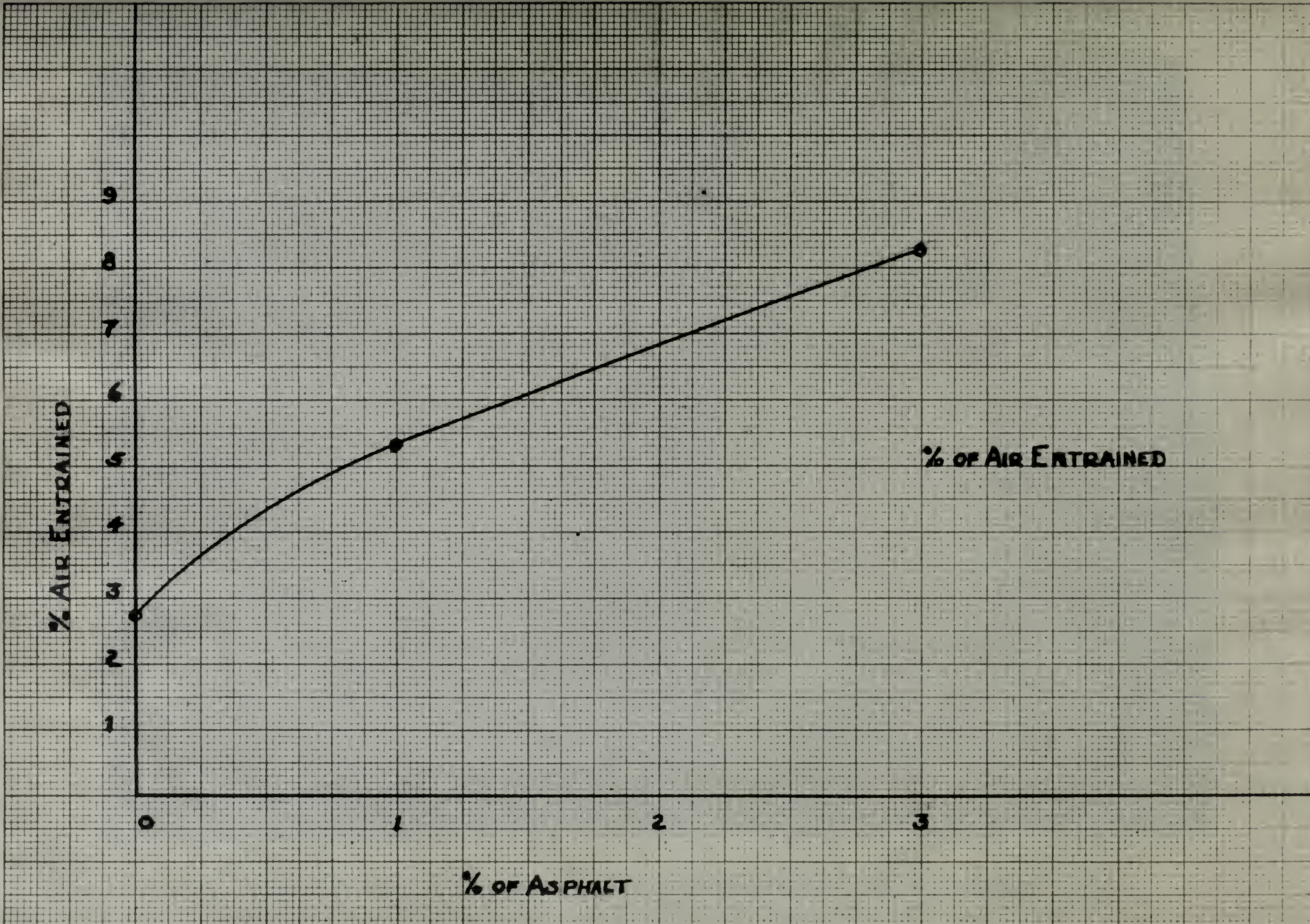
TESTED May 7, 1948

Percent of Asphalt	Breaking Load	P.S.I.	Average
	22700	3215	
0	26600	3770	3607
	27100	3836	
	15300	2165	
1	16400	2322	2247
	15800	2224	
	15300	2165	
2	15500	2195	2200
	15800	2240	
	9000	1273	
3	11900	1686	1675
	14600	2068	


COMPRESSIVE TEST
OF 35 DAY CYLINDERS
AFTER 3-24 HOUR FREEZE
THAW CYCLES
ULTIMATE STRENGTH P.S.I.
4000
3000
2000
1000
0
1
2
3
4
% OF ASPHALT



STRENGTH
VS
TIME
CURVES
1 - 0% ASPHALT
2 - 1% "
3 - 2% "
4 - 3% "
ULTIMATE STRENGTH PSI
4000
3000
2000
1000
0
10
20
30
40
50
TIME DAYS


% of Air Entrained
% Air Entrained
1
2
3
4
5
6
7
8
9
0
1
2
3
% of Asphalt

Cross Sectional View Of Concrete Beams Containing Admixture

Dark Areas Are Asphalt Inclusions

Typical Fracture Of Concrete Beams

Typical Fractures of Concrete Cylinders
Left To Right: 0, 1, 2, 3 % Emulsion

CONCLUSIONS

At this stage of the investigation it must be concluded that the results are essentially negative.

The authors, however, feel that the subject warrants further study. While the results shown indicate adverse effects on strength of concrete containing asphalt emulsion, a small reduction of strength can be tolerated if other desirable properties are improved. In general no marked improvement of properties with the exception of air-entrainment was observed. It must be realized, however, that necessarily only one type of emulsion was used; that short-time tests were conducted; that arbitrary methods of mixing were used; and that a particular cement, aggregate, and sand were used. Obviously then, there is much further research to be carried on before the idea of using an asphaltic emulsion as an admixture in concrete should be abandoned.

Further consideration should be given to the selection of the particular asphaltic emulsion best suited, as the particle size in different emulsions ranges from very fine to very coarse, or from about one micron to ten microns. "An emulsion being essentially a disperse system, its state of dispersion is necessarily one of its most important characteristics. Two aspects of the degree of dispersion are important: (1) The mean absolute size of the particles, and (2) The range size of the particles and their distribution throughout the range size".

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Many valuable properties could be investigated by tests requiring much longer periods of time. Among these can be included the control of temperature stresses due to the expansion and contraction of concrete through the reaction between cement and aggregate (ref. Paper 2129, ASCE Transactions, Vol. 107, p. 54, 1942).

In practice, the advantages of air entrainment upon the durability of concrete have been exhibited only after years of being subjected to the freezing and thawing forces of nature. The fact that the amount of air entrained in concrete mixtures can be controlled by the addition of definite amounts of asphaltic emulsion indicates that this material will at least accomplish the same result as other commercial products used for this purpose. To obtain maximum information from the proposed freeze-thaw test, a far greater number of cycles should be completed before results can be considered conclusive.

Overcoming the macroscopic segregation of the asphaltic material appears to be the major problem before the full capabilities of the admixture can be realized. Many methods, applicable to laboratory use, become impractical in the field. It is suggested, however, that a better distribution might be obtained by spraying it over the wet mix and then continuing mixing until the asphalt is uniformly distributed throughout the plastic mass.

As has been stated before, in a work of this type, there are many variables which must be considered and certain arbitrary choices had to be made. In view of this fact, perhaps other cements and other aggregates might also be used in future research.

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January 2, 1947

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